Next Generation Space Telescope

Integrated Science Instrument Module

Technology Development Requirements and Goals for the NGST Detectors

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1.0 INTRODUCTION

The Integrated Science Instrument Module (ISIM) is the payload of the Next Generation Space Telescope (NGST).

The ISIM includes the following:

- Facility sensor
  - Fine Guidance Sensor (FGS)
- Science Instruments (SI)
  - Near Infrared Camera (NIRCam)
  - Near Infrared Spectrometer (NIRSpec)
  - Mid Infrared Instrument (MIRI)
- Associated/shared subsystems
  - Structure
  - Thermal Control
  - Command and Data Handling (C&DH) hardware and software
  - Front-end electronics (Analog/Digital [A/D] conversion)
  - Focal plane (detector) control electronics

1.1 SCOPE

The NGST ISIM Project will be providing the Science Instrument Principal Investigator/Instrument Development Teams with the instrument focal plane assembly (FPA) and associated control and data handling electronics. Two detector technologies are being developed for use in the FPAs.

The NGST Detector Requirements Panel, in developing their recommendations (NGST-RPT-000425, NGST public web site download document #538), recognized the desirability of recommending (1) a reasonable, hopefully achievable standard of performance that the mission really *must* have (the "Requirement"), and (2) a second, significantly-more-challenging, yet desirable standard that would provide substantially more scientific return (the "Goal"). The panel tried to balance the needs outlined in NGST science objectives, with a practical view of what the technology providers could reasonably be expected to deliver in the ~3-year NGST technology development time frame. For the near-IR, the Requirement would be to achieve zodiacal background-limited performance for imaging, up to a spectral resolution of 10, at a wavelength 2 μm. NIR Goals would go beyond this, addressing higher-resolution imaging, and the needs of spectroscopy. The same approach applied to the mid-IR, with the reference wavelength being 10 μm. Note that the Goals, in some cases, stopped short of the most extraordinary background-limited performance levels associated with the shorter-wavelength, highest-resolution spectroscopy.

This document establishes the requirements and goals for the detector technology developments.

2.0 APPLICABLE DOCUMENTS

The following documents provide information applicable to the contents of the document as well as basic information used in its generation. These documents are subject to periodic revision, the user, therefore, should refer to the latest available version. In the event of a conflict between documents referenced herein and the requirements of this document, the requirements of this document shall take precedence.

2.1 DOCUMENTS

2.1.1 GSFC Documents

Document Number	Document Title
NGST-REQT-000633	NGST Level 1 Requirements
NGST-REQT-000634	NGST Level 2 Requirements
ngst.nasa.gov/science/drm.html	NGST Design Reference Mission
NGST-IRD-000728	Near Infrared Camera Interface Requirements Document
NGST-IRD-000729	Near Infrared Spectrometer Interface Requirements Document
NGST-IRD-000730	Mid Infrared Instrument Interface Requirements Document
NGST-RPT-000524	A Note on NGST Detector Modulation Transfer Function Guidelines
NGST-RPT-000453	The Radiation Environment for the NGST

2.1.2 Non-GSFC Documents

Document Number	Document Title

2.2 DRAWINGS

2.2.1 GSFC Drawings

Drawing Number	Drawing Title

2.2.2 Non-GSFC Drawings

Drawing Number	Drawing Title

3.0 DESIGN REQUIREMENTS/GOALS

3.1 NEAR INFRARED REQUIREMENTS/GOALS

3.1.1 Detector Driven Requirements/Goals

Parameter	Requirement[1]	Goal[2]	Rationale
FPA Format	n x m, where n and m are integer multiples of 2048	n x m, where n and m are integer multiples of 2048	Maintain 2048 x 2048 in SCA format trade space and maintains electrical independence at the 2048 x 2048 level.
SCA Format	1-4 Mpixel. Reference pixels may be located within, or outside of, the 2048 pixel field.	1-4 Mpixel. Reference pixels may be located within, or outside of, the 2048 pixel field.	Cost/Benefit trade
Total Noise per pixel[3]	9 e^- rms	2.5 e^- rms	Allows photon-noise-limited observations. Maximizes signal/noise.
Read noise			Not quantified, to allow latitude in focal plane design and operating point.
Shot noise in dark current			Not quantified, to allow latitude in focal plane design and operating point.
QE[4]	≥70% for $0.6 < \lambda < 1.0$ μm; ≥80% for $1 < \lambda < 5$ μm.	≥90% for $0.6 < \lambda < 1.0$ μm; ≥95% for $1 < \lambda < 5$ μm.	Maximizes signal (and signal/noise). Also, consistent with QEs achieved by candidate technologies.
Well Capacity	6×10^4 e^-	2×10^5 e^-	Consistent with mission objectives, and technologically feasible.
Pixel Operability[5]	>98% (TBR)	>99.5% (TBR)	Cost/Benefit trade, to be resolved; see Monograph 5 (document 744).
Linearity	TBD	TBD	Cost/Benefit trade, to be determined
Pixel-to-Pixel Uniformity	TBD	TBD	Cost/Benefit trade, to be determined
Radiometric Stability	TBD	TBD	Cost/Benefit trade, to be determined
Bad Pixel Clustering	TBD	TBD	Cost/Benefit trade, to be determined
Latent or Residual Images[6]	order of 0.1% (1st read after saturating exposure)	0%	Consistent with SIRTF findings, and with NGST observational planning.

Parameter	Requirement[1]	Goal[2]	Rationale
Min / Max Wavelength	0.6 – 5 μm, for imaging and spectroscopy	0.6 – 5 μm	Covers key spectral range in NGST science objectives; provides linkage to optical range.
Fill Factor	>95%	100%	Maximizes signal/noise; technologically feasible.
Radiation Immunity[7]	<4% pixels out of spec at end of 5 year mission. (TBR)	No effect. (TBR).	Allows a factor of two degradation but ensures detectors will last until end of mission life.

3.1.2 System Driven Requirements/Goals

Parameter	Requirement[1]	Goal[2]	Rationale
Number of Detectors	48 Mpixels for imaging, and 16 Mpixels for spectroscopy. (TBR)	--	Limited by power dissipation and cost constraints.
Frame Time[8]	12 s	<12 s	Determined by assumed pixel time of 10 μs, number of outputs, and pixel dimensions.
Temperature	Meet all requirements at temperature T, where 30 ≤ T ≤ 37 K	Meet all requirements within a temperature band extending 2 K above and 2 K below the selected T. If the selected T is within 2 K of 30 or 37 K, the goal is to meet all requirements throughout as much of the ±2 K band that does not violate the 30 or 37 K endpoints.	30 K is determined by lowest feasible passively-cooled focal plane temperature. Under present assumptions, 37 K is highest temperature consistent with adequate Mid IR instrument performance..
Power Dissipation (at FPA temp)	1 mW per Mpixel	0.1 mW per Mpixel	Extrapolated from SIRTF experience on smaller but similar arrays.
Pixel Pitch[9]	18 - 25 μm	18 - 25 μm	Minimum dimension, consistent with current industrial capabilities. Minimizes leakage current, cosmic ray cross-section, and pixel capacitance.

Parameter	Requirement[1]	Goal[2]	Rationale
MTF[10]	0.53	>0.53	Driven by spectroscopy: contrast should be degraded by no more than 10% for critically-sampled spectra. (For imaging, encircled energy should be degraded by no more than 10% by detector MTF.)
Cosmic Ray Pixel Upsets[11]	<10%	<2%	Estimates derived from detailed analysis of clusters of pixels affected, in SIRTF proton irradiation experiments.
Maximum Exposure Time	1000 s	>1000 s	Determined by assumed cosmic event flux of ~4 /cm^2-s, and ability to accept approximately 5% of array pixels affected by cosmic events.
Wavefront Sensing–Subarray Operation[12]	Variable subarray or subarrays. The timing requirement is 128 pixels x 128 pixels with 0.2 seconds integration time, using correlated double sampling. Frame time is TBD	Variable subarray or subarrays. The timing goal is 128 pixels x 128 pixels with less than 0.2 seconds integration time, using correlated double sampling. Frame time is TBD	Intermediate subarray formats needed to capture light from significantly out-of-focus star images during observatory setup.

3.1.3 NIR Requirements/Goals Notes

1) The Requirement is generally the level of performance consistent with zodiacal-background-limited broadband imaging ($\lambda/\Delta\lambda$ <10) at 3 μm. These Requirements are considered a hard minimum for the mission.

2) The Goal is often, but not always, associated with the level of of performance consistent with background-limited spectroscopic ($\lambda/\Delta\lambda$ ~100) observations at 3 μm. Furthermore, the sense of the values for Goals is that these are clearly desirable, but are intentionally optimistic and very challenging.

3) Quadrature sum of contributions from read noise, shot noise on dark current, shot noise on glow, 1/f, timing fluctuations, temperature drifts, temperature gradients across array, etc. To enhance observational efficiency, it is strongly desired that the read noise values consistent with the stated noise totals be achieved with the minimum number of samples, and/or in the minimum overall time. The target number of Fowler samples, to achieve read noise levels consistent with these overall Requirement & Goal noise levels, is 8. Given the baseline 1000 s exposure time and a ≤12 s frame time constraints, the contractor will be free to optimize read noise performance by trading numbers-of-samples against pixel times, or other variations, to achieve the stated Requirement and Goal noise levels. Noise data may be obtained by

frame subtraction (spatial variation) or per-pixel sampling (temporal variation) techniques, as appropriate and validated.

Furthermore, these Requirement and Goal detector noise values have been chosen to accommodate anticipated electronics and cable noise contributions, so as to maintain 10 and 3 e-, respectively, as system-level Requirements and Goals for noise.

4) Quantum efficiency specifications apply as a minimum QE anywhere within the spectral range.

5) For a given pixel to be 'operable', it must simultaneously meet requirements (or goals) in certain parameters judged to be key (e.g., total noise, QE, and latent images; (TBR)).

6) It is important to measure the latent/residual image at the same integration time as was used to saturate.

7) Need minimal or no effect on key parameters like responsivity, read noise, dark current.

8) Shorter frame time desired as goal. Current value limited by power budgets for data conversion (A/D) electronics and FPA.

9) This Requirements Document is a point of coordination between our detector development program and other engineering efforts across the NGST system. The range on pixel pitch given in this document is set to be no wider than necessary to encompass the design approach that each known potential supplier has chosen. From time to time, this range may change to reflect the design approach of known potential suppliers. Such changes should not be construed as a preference for any given technology or supplier. It is planed that this document will be used to inform NIRCam AO offerors and NIRSpec development contractors of what they should assume about characteristics of detectors that NGST will provide as GFE. It is expected that all NIRCam proposals and NIRSpec development work will be compatible with the full envelope of the parameter space defined therein.

10) See "A Note on NGST Detector Modulation Transfer Function Guidelines," (http://ngst.gsfc.nasa.gov/cgi-bin/pubdownload?Id=662.) MTF specifications to be met at 2 μm wavelength.

11) Fraction of pixels above total noise specification after a 1000 s integration in a cosmic ray flux of 5 s^{-1} cm^{-2} . See http://ngst.gsfc.nasa.gov/cgi-bin/pubdownload?Id=570 for information on NGST radiation environment.

12) Wavefront-sensing subarray window location to be selectable over any location in all Sensor Chip Assemblies (SCAs). Also, wavefront sensing and science measurement modes will not be exercised simultaneously. That is, when operating in sub-array mode, pixels outside the sub-array are not expected to meet requirements / goals, and they may become non-operable.

13) Overall Note: The 'System Driven' parameters can be considered independent variables. The temperature, power dissipation, pixel pitch, MTF, and exposure time characteristics are either determined by overall system designs, or are within the range of reasonable detector design / tradeoff /optimization space.

3.2 MID INFRARED REQUIREMENTS/GOALS

3.2.1 Detector Driven Requirements/Goals

Parameter	Requirement[1]	Goal[2]	Rationale
FPA Format	1024 x 1024	1024 x 1024	Covers desired field of view with diffraction-limited pixels.
SCA Format	1 Mpixel. Reference pixels may be located within, or outside of, the 1024 pixel field.	1 Mpixel. Reference pixels may be located within, or outside of, the 1024 pixel field.	Cost/Benefit trade
Total Noise[3]	19 e^- rms	2.5 e^- rms	Allows photon-noise-limited observations. Maximizes signal/noise.
Read noise			Not quantified, to allow latitude in focal plane design and operating point.
Shot noise in dark current			Not quantified, to allow latitude in focal plane design and operating point.
QE[4]	>50%	>60%	Maximizes signal (and signal/noise). Also, consistent with QEs achieved by candidate technologies.
Well Capacity	1 x 10^5 e^-	>2 x 10^5 e^-	Consistent with mission objectives, and technologically feasible.
Pixel Operability[5]	>98% (TBR)	>99.5% (TBR)	Cost/Benefit trade; see Mongraph 5 (document 744).
Linearity	TBD	TBD	Cost/Benefit trade, to be determined
Pixel-to-Pixel Uniformity	TBD	TBD	Cost/Benefit trade, to be determined
Radiometric Stability	TBD	TBD	Cost/Benefit trade, to be determined
Bad Pixel Clustering	TBD	TBD	Cost/Benefit trade
Latent or Residual Images[6]	order of 0.1% (1st read after saturating exposure)	<0.1%	Consistent with SIRTF findings, and with NGST observational planning.
Min / Max Wavelength	5 - 27 μm	5 – 30 μm	Covers key spectral range in NGST science objectives.

Parameter	Requirement[1]	Goal[2]	Rationale
Fill Factor	~100 %	100 %	Maximizes signal/noise; technologically feasible.
Radiation Immunity[7]	<4% pixels out of spec at end of 5 year mission. (TBR)	No effect. (TBR).	Allows a factor of two degradation but ensures detectors will last until end of mission life.

3.2.2 System Driven Requirements/Goals

Parameter	Requirement[1]	Goal[2]	Rationale
Number of Detectors	1 Mpixel (TBR)	1 Mpixel (TBR)	Limited by power dissipation and cost cost constraints
Frame Time[8]	3 s	<3 s	Determined by assumed pixel time of 10 μs, number of outputs, pixel dimensions, & commonality with NIR.
Temperature	6.7 K	>6.7 K	Temperature anticipated necessary needed to achieve ~0.01 e^-/s dark current.
Power Dissipation (at FPA temp)	1 mW per Mpixel	0.1 mW per Mpixel	Extrapolated from SIRTF experience on smaller but similar arrays.
Pixel Pitch	18 - 30 μm / tradeoff	18 - 30 μm / tradeoff	Dimensions consistent with current industrial capabilities.
MTF[9]	0.53	>0.53	Driven by spectroscopy: contrast should be degraded by no more than 10% for critically-sampled spectra. (For imaging, encircled energy should be degraded by no more than 10% by detector MTF.)
Cosmic Ray Pixel Upsets[10]	<18%	<4%	Estimates derived from detailed analysis of clusters of pixels affected, in SIRTF proton irradiation experiments.

Parameter	Requirement[1]	Goal[2]	Rationale
Maximum Exposure Time	1000 s	>1000 s	Determined by assumed cosmic event flux of ~4 /cm^2-s, and ability to accept approximately 5% of array pixels affected by cosmic events.
Electrical Redundancy	Redundant electrical configuration (for clocks, biases, outputs). 4 outputs per Mpixel.	Redundant electrical configuration (for clocks, biases, outputs). 4 outputs per Mpixel.	Prevents loss of MIR channel from single-point electrical failures. Implemented at multiplexer level, multiple-SCA designs, or other suitable means.

3.1.3 MIR Requirements/Goals Notes

1) The Requirement is generally the level of performance consistent with zodiacal-background-limited broadband imaging ($\lambda/\Delta\lambda$ <10) at 5 μm. These Requirements are considered a hard minimum for the mission

2) The Goal is often, but not always, associated with the level of of performance consistent with background-limited spectroscopic ($\lambda/\Delta\lambda$ ~100) observations at 5 μm. Furthermore, the sense of the values for Goals is that these are clearly desirable, but are intentionally optimistic and very challenging.

3) Quadrature sum of contributions from read noise, shot noise on dark current, shot noise on glow, 1/f, timing fluctuations, temperature drifts, temperature gradients across array, etc. To enhance observational efficiency, it is strongly desired that the read noise values consistent with the stated noise totals be achieved with the minimum number of samples, and/or in the minimum overall time. The target number of Fowler samples, to achieve read noise levels consistent with these overall Requirement & Goal noise levels, is 8. Given the baseline 1000 s exposure time and a ≤12 s frame time constraints, the contractor will be free to optimize read noise performance by trading numbers-of-samples against pixel times, or other variations, to achieve the stated Requirement and Goal noise levels. Noise data may be obtained by frame subtraction (spatial variation) or per-pixel sampling (temporal variation) techniques, as appropriate and validated.

Furthermore, these Requirement and Goal detector noise values have been chosen to accommodate anticipated electronics and cable noise contributions, so as to maintain 20 and 3 e-, respectively, as system-level Requirements and Goals for noise.

4) Quantum efficiency specifications apply as a minimum QE anywhere within the spectral range.

5) For a given pixel to be 'operable', it must simultaneously meet requirements (or goals) in certain parameters judged to be key (e.g., total noise, QE, and latent images; (TBR)).

6) It is important to measure the latent/residual image at the same integration time as was used to saturate.

7) Need minimal or no effect on key parameters like responsivity, read noise, dark current.

8) Shorter frame time desired as goal. Current value limited by power budgets for data conversion (A/D) electronics and FPA.

9) See "A Note on NGST Detector Modulation Transfer Function Guidelines," (http://ngst.gsfc.nasa.gov/cgi-bin/pubdownload?Id=662.) MTF specifications to be met at 10 μm wavelength.

10) Fraction of pixels above total noise specification after a 1000 s integration in a cosmic ray flux of 5 s^{-1} cm^{-2} . See http://ngst.gsfc.nasa.gov/cgi-bin/pubdownload?Id=570 for information on NGST radiation environment.

11) Overall Note: The 'System Driven' parameters can be considered independent variables. The temperature, power dissipation, pixel pitch, MTF, and exposure time characteristics are either determined by overall system designs, or are within the range of reasonable detector design / tradeoff / optimization space.

APPENDIX A. ABBREVIATIONS AND ACRONYMS

Appendix A. Abbreviations and Acronyms

A/D	Analog/Digital
C&DH	Command and Data Handling
cm	Centimeter
CMO	Configuration Management Office
f	frequency
FGS	Fine Guidance Sensor
FPA	Focal Plane Assembly
GSFC	Goddard Space Flight Center
IR	Infrared
ISIM	Integrated Science Instrument Module
K	Kelvin
M	Mega
max	Maximum
min	Minimum
MIRI	Mid Infrared Instrument
MTF	Modulation Transfer Function
mW	Milliwatt
NASA	National Aeronautics and Space Administration
NGST	Next Generation Space Telescope
NIRCam	Near Infrared Camera
NIRSpec	Near Infrared Spectrometer
QE	Quantum Efficiency
rms	Root Mean Square
RQMT	Requirement
s	Second
SCA	Sensor Chip Assembly
SI	Science Instrument(s)
SIRTF	Space Infrared Telescope Facility
T	Temperature
TBD	To be determined
TBR	To be reviewed
µm	Micrometer
µs	Microsecond